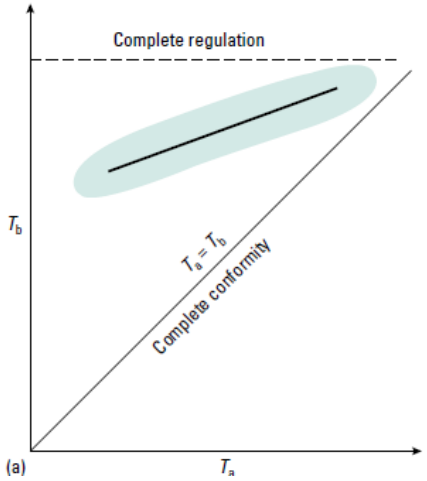
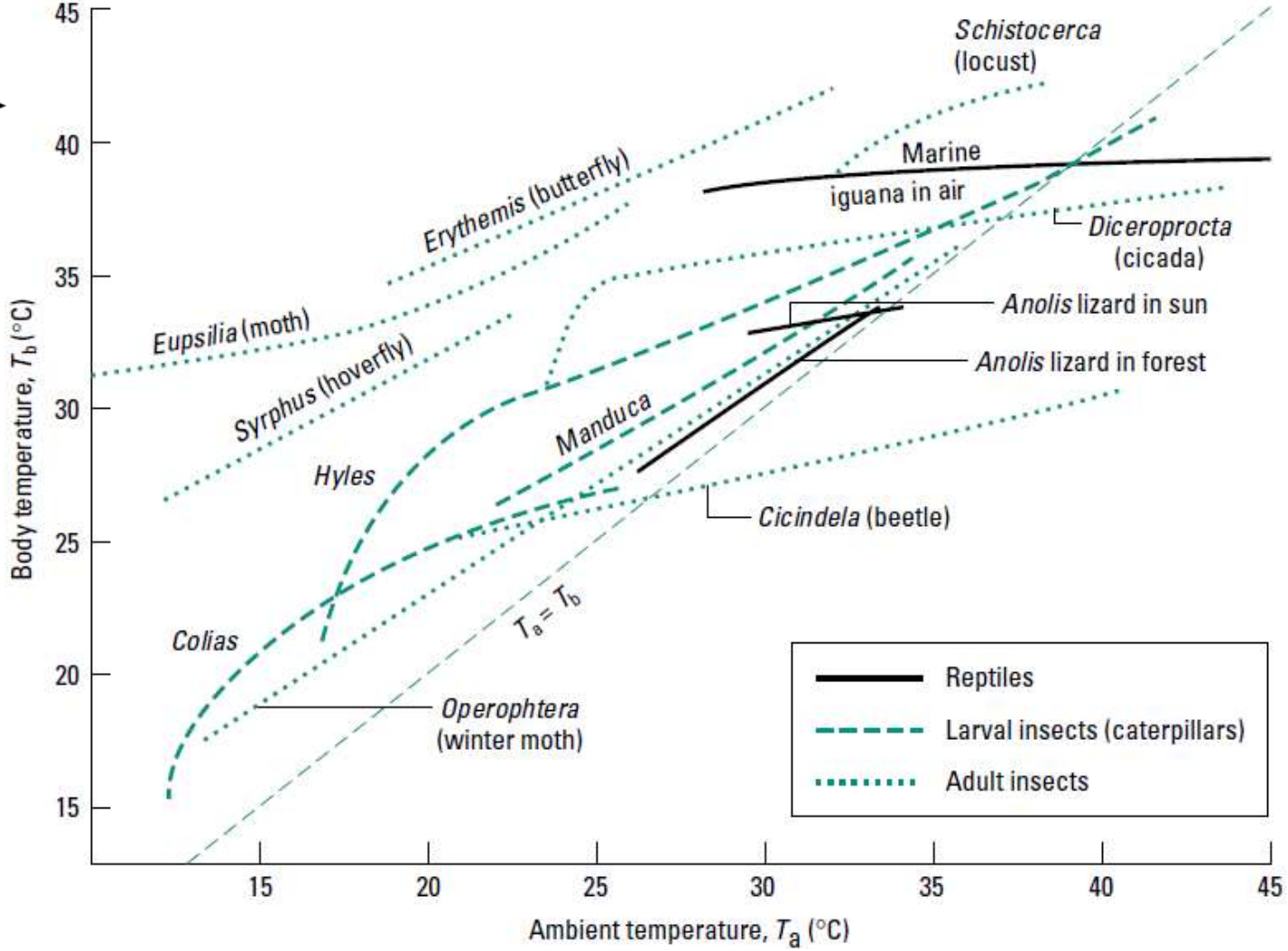
3. Thermal regulation, tolerance, and avoidance

Thermoconformers and thermoregulators



Anolis lizard



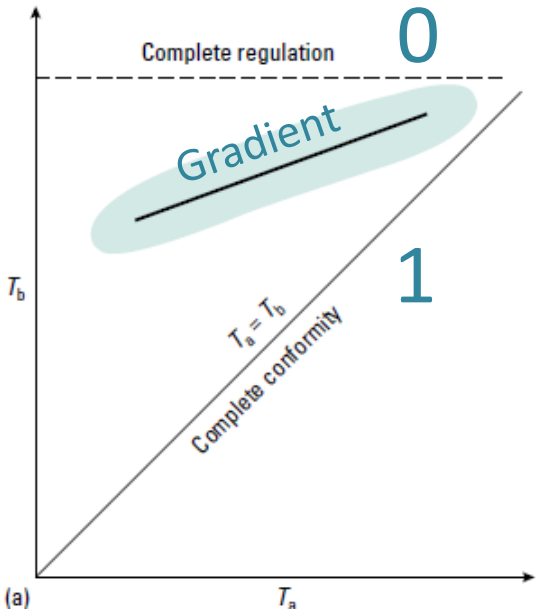


Table 15.10 Gradients of regression of body temperature (T_b) on ambient temperature (T_a) in terrestrial animals.

Animal	Gradient
Ectotherms	
Anolis lizard (forest)	1.17
Tenebrionid beetle	1.00
Salamander	1.00
Python (non-brooding)	0.48
Cicada (non-singing)	0.44
Anolis lizard (grassland)	0.43
Sphinx moth caterpillar	0.40
Heterotherms	
Honey-bee	0.81
Solitary bee (foraging)	0.65
Honey-bee (foraging)	0.55
Dragonfly	0.43
Naked mole rat	0.41
Bumble-bee (foraging)	0.23
Python (brooding)	0.12
Bumble-bee (brooding)	0.07
Endotherms	
Pocket mouse	0.08
Possum	0.07
Finch	0.05
Parrot	0.05
Weasel	0
Human	0

Behavioural thermoregulation

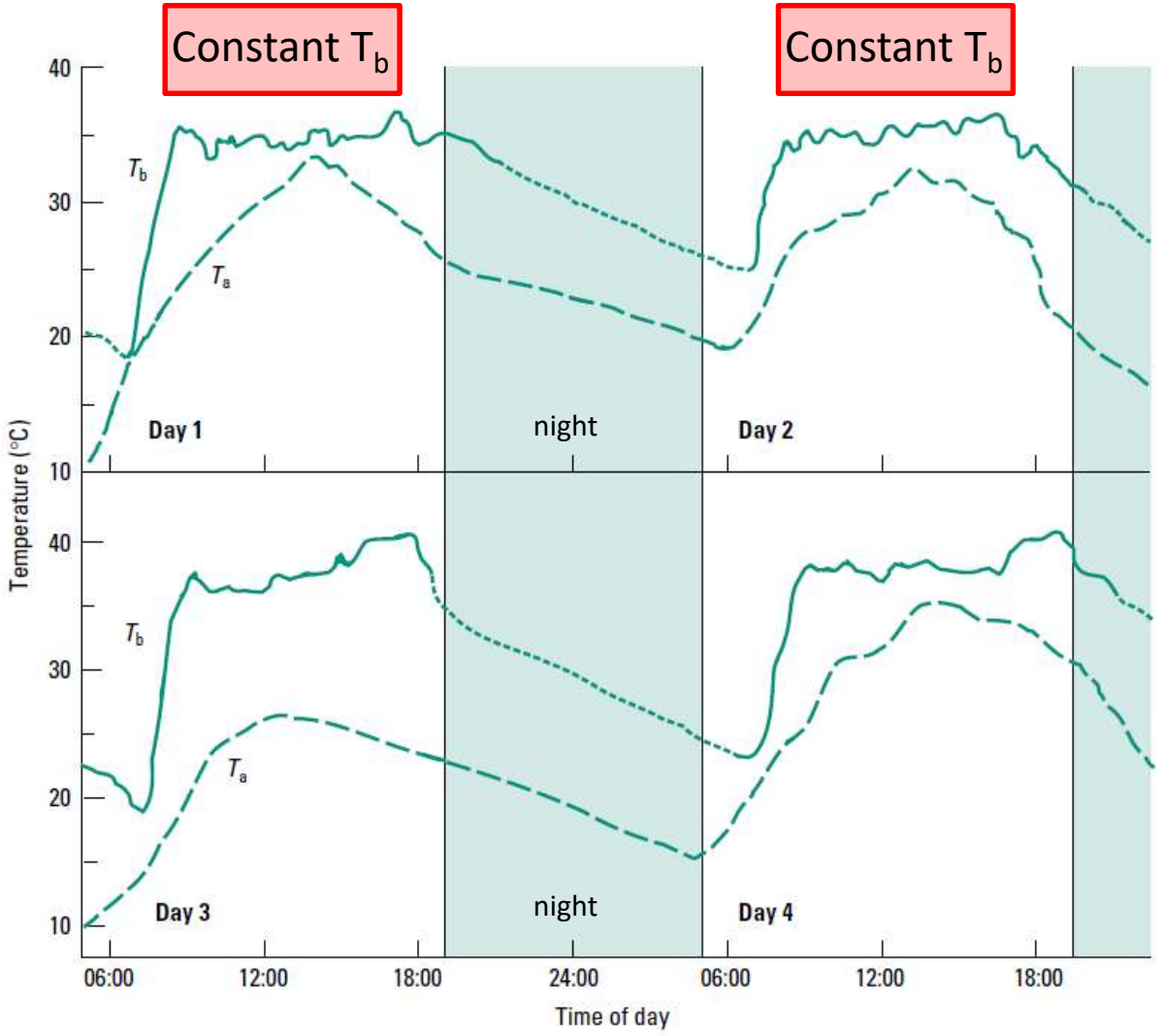
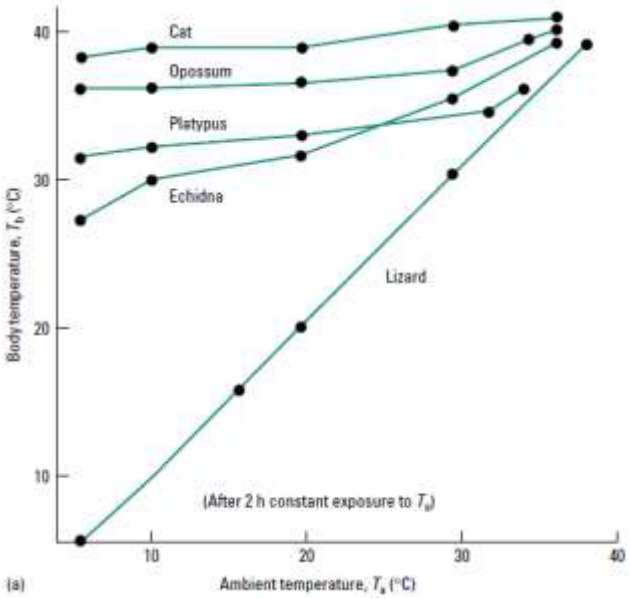


Fig. 15.23 Patterns of temperature through a day for a *Varanus* monitor lizard, measured by telemetry, showing the rapid rise in body temperature (T_b) (to well above ambient temperatures, T_a) due to early-morning basking and subsequent effective thermoregulation through the daylight hours by sun–shade shuttling. Note that the lizard has high thermal inertia curled in its treehole den at night so that T_b falls quite slowly. (From Cossins & Bowler 1987, with kind permission from Chapman & Hall.)

Physiological thermoregulation

- Mammals and Birds
- Brooding pythons



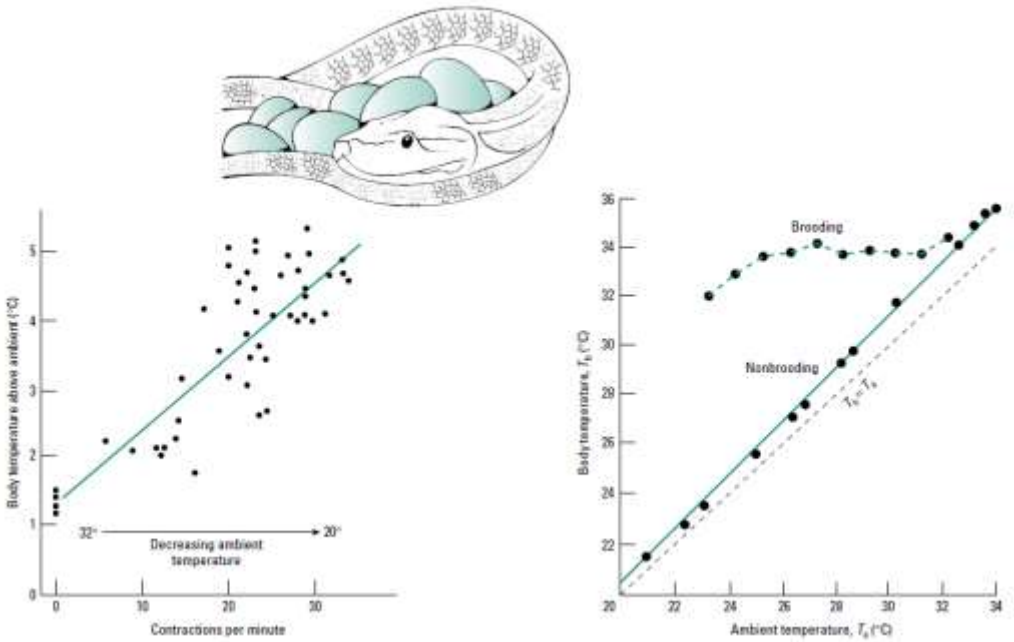


Fig. 15.28 Thermogenic incubation in a python; curled around her eggs, the female contracts her trunk muscles rhythmically to raise metabolic rate and increase T_b. (Adapted from Hutchinson *et al.* 1966; van Mierop & Barnard 1978.)

Fig. 15.26 (a) Plots of body temperature (T_b) against ambient temperature (T_a) for endothermic mammals and a lizard in laboratory studies, showing the better regulation in the eutherian cat compared with monotremes and marsupials. (b)

Counter-current heat exchange

- Counter-current exchange retains heat

Peripheral

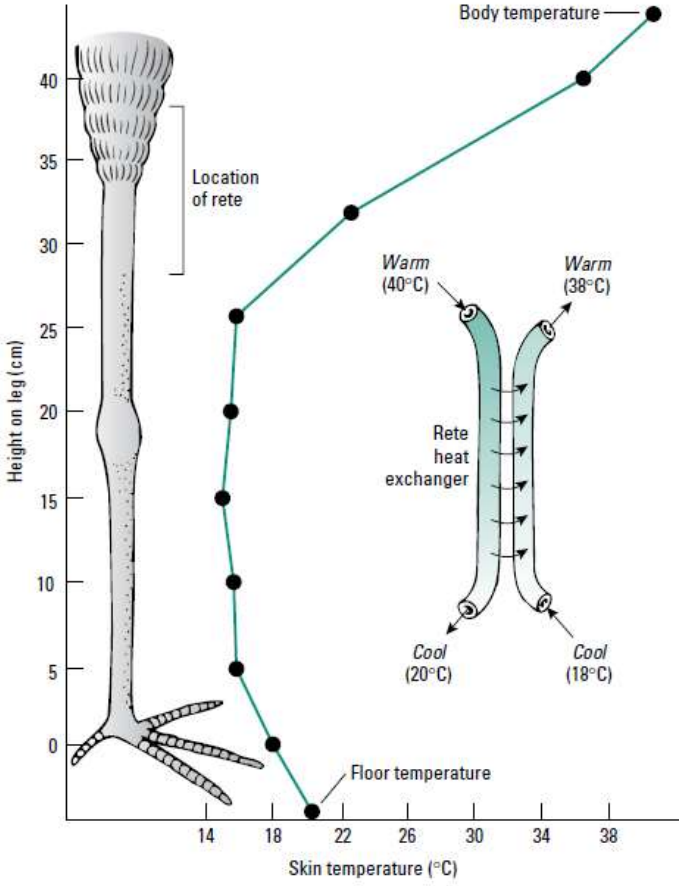
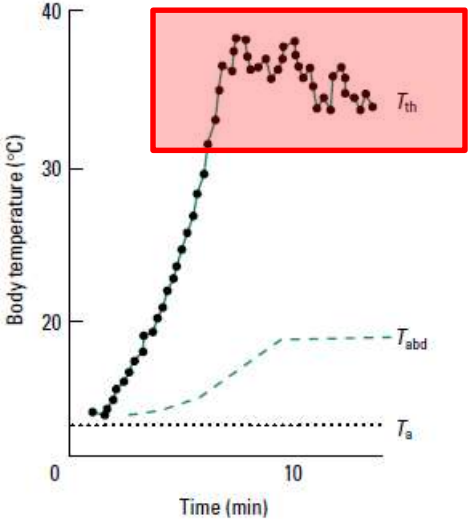
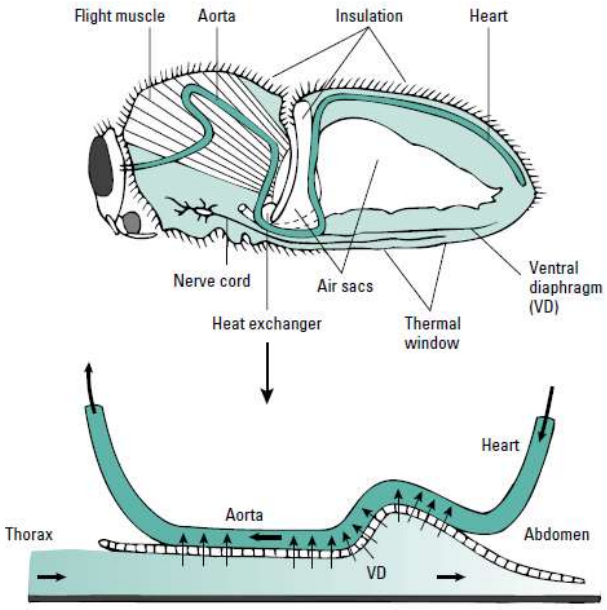


Fig. 15.32 Temperatures recorded from skin surface along the leg of a wood stork, showing the heat-conserving effect of an upper limb countercurrent rete.

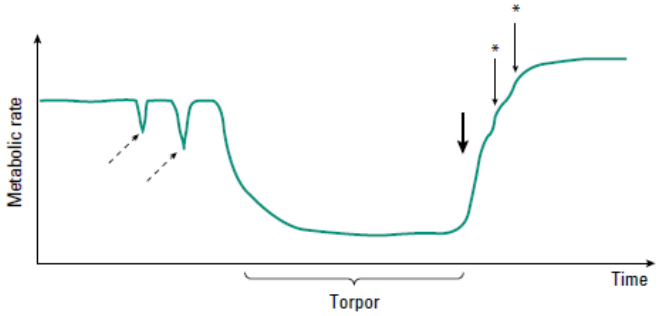
Bumblebee

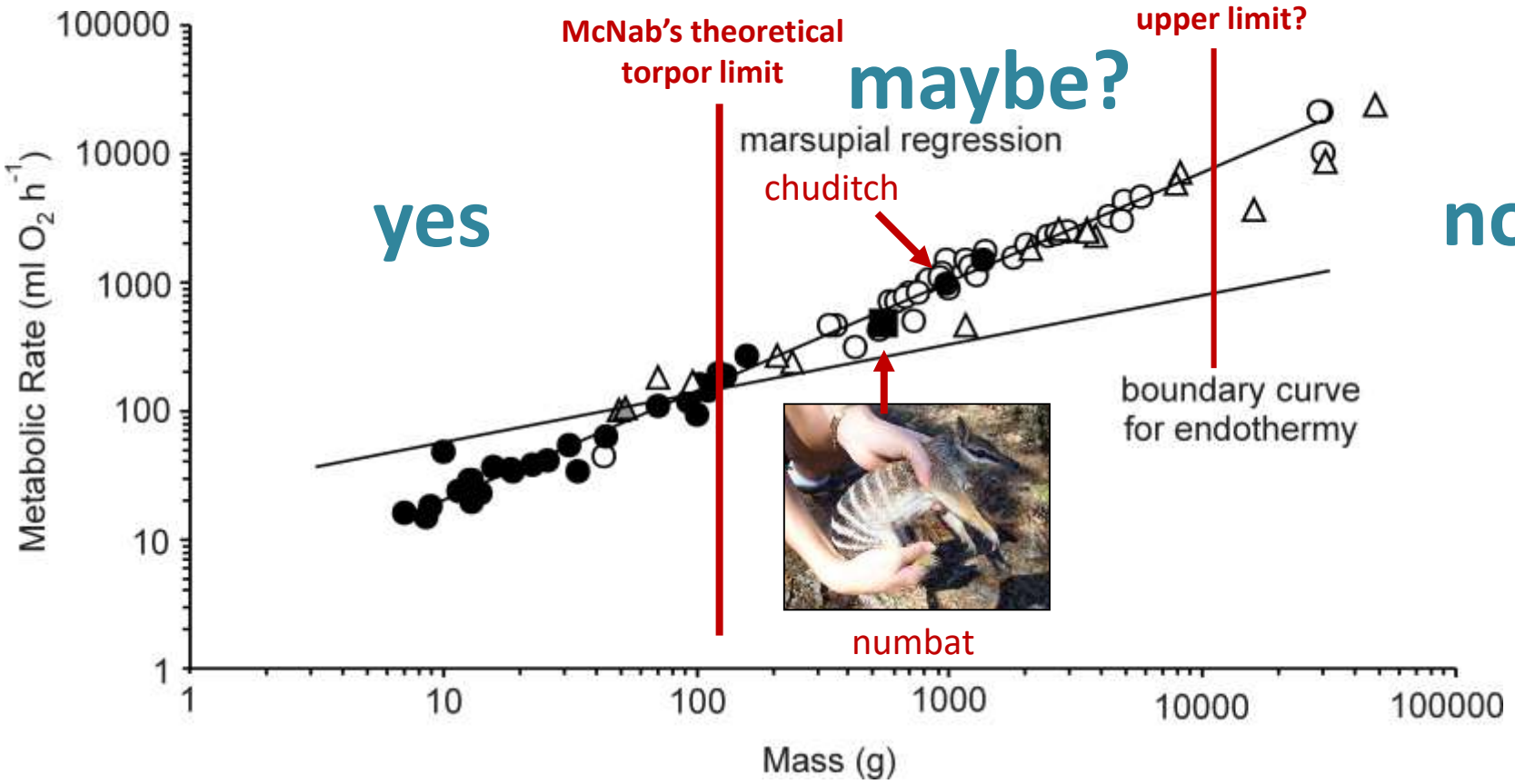


Thorax-abdomen



Torpor – seems to be size limited





Relationship between metabolic rate and body mass for 63 species of marsupial, where species know to utilise torpor are shown with filled circles and those not known to utilise torpor with open circles. = Data from McNab (1984), Geiser (1994, 2003) and Withers *et al*. (2000).

Three main strategies in hot dry environments

Desert toad

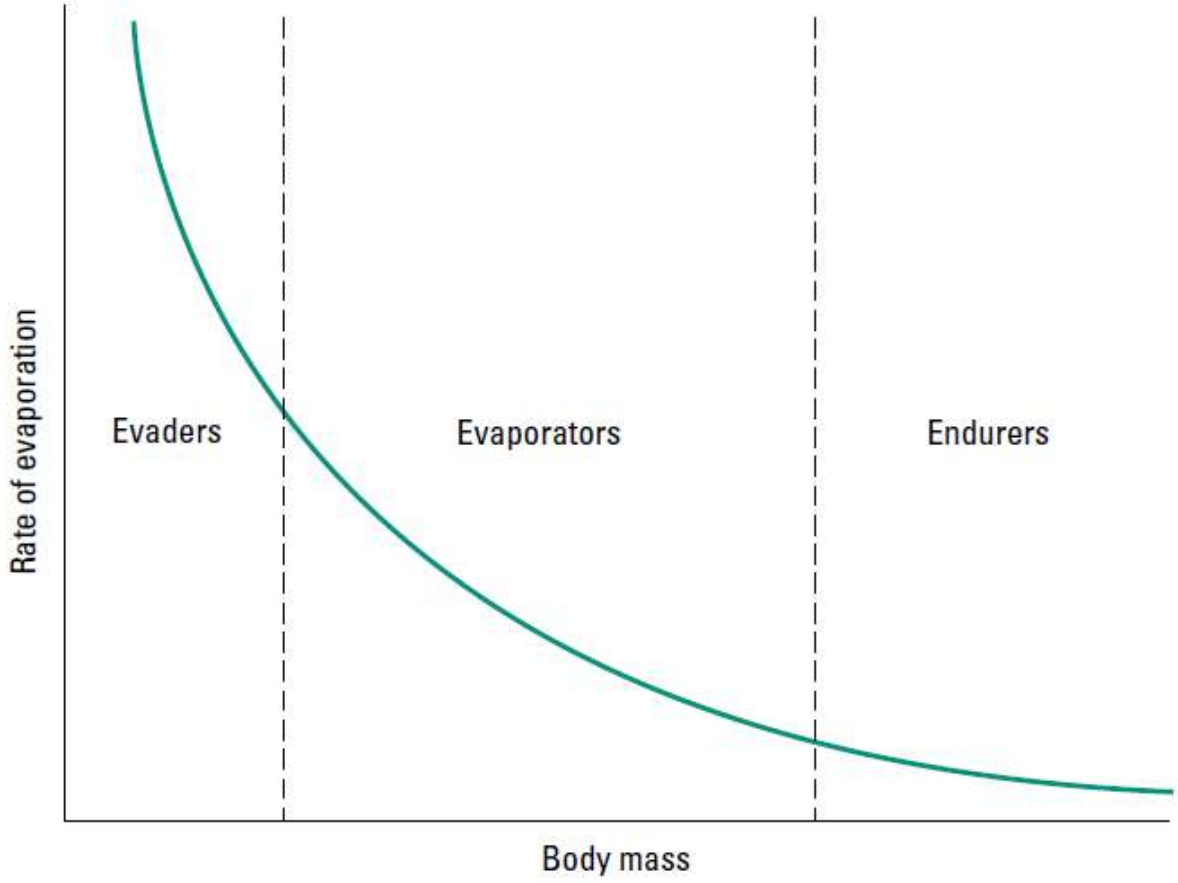


Fig. 16.7 Three main strategies for desert animals, in relation to size and rate of evaporation.

Strategies in hot dry environments

Evaders

- **Burrows**
- **Mobility**
- Rhythmicity
- **Tolerance**
- Colour, shape, posture
- **Tolerance of EWL**
- Water uptake
- Respiration
- **Microclimate control**
- **Food selection**
- **Aestivation**
- Reproduction
- **Sociality**

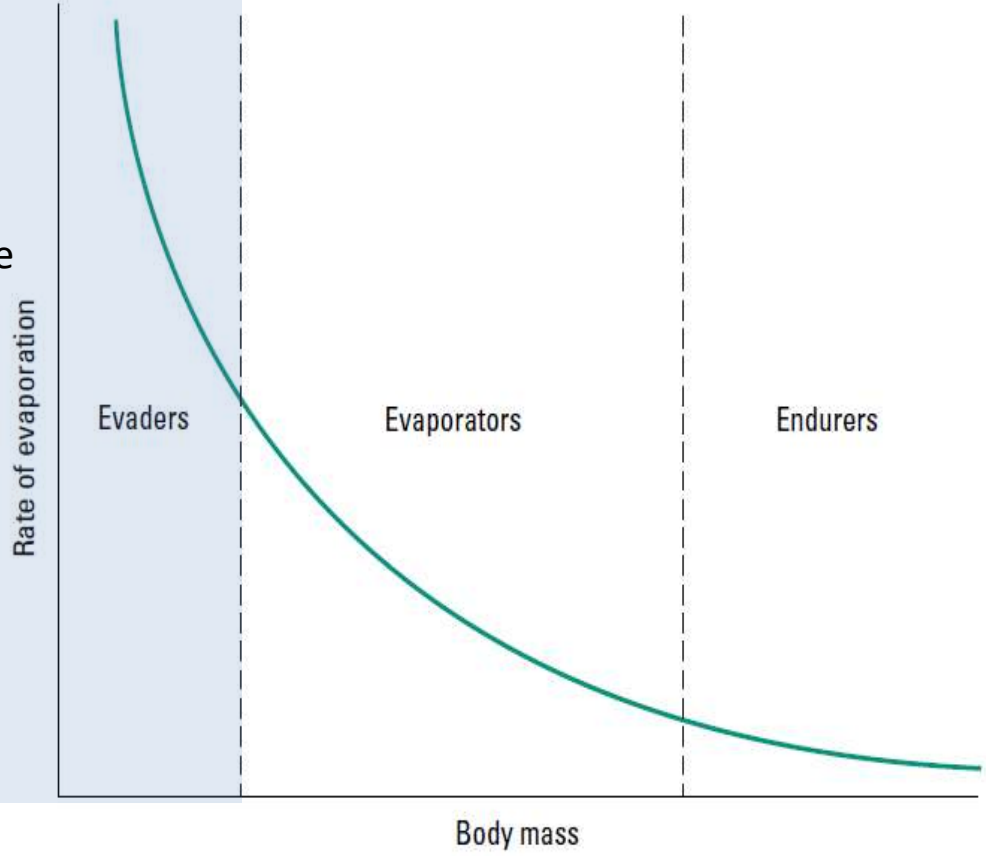
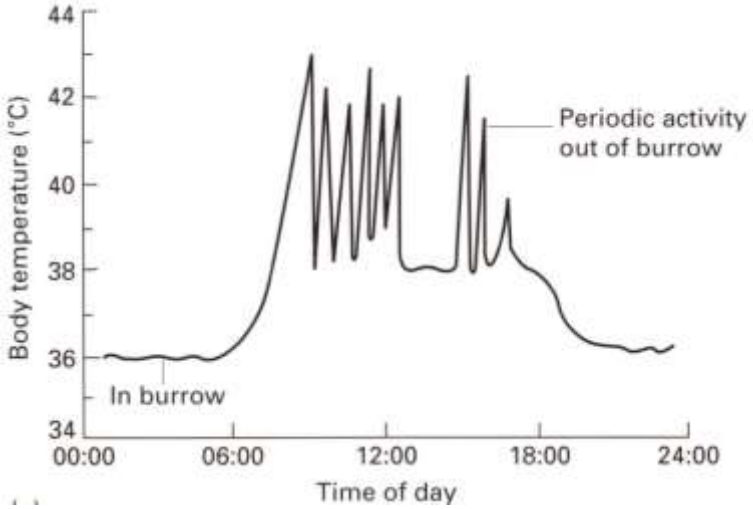
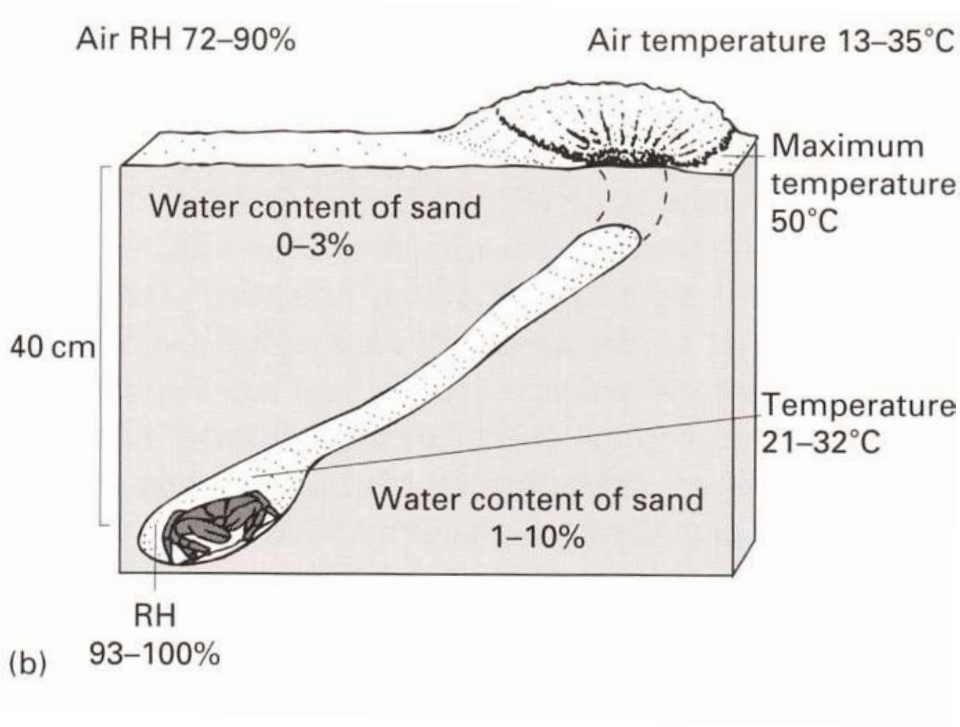


Fig. 16.7 Three main strategies for desert animals, in relation to size and rate of evaporation.

Burrows

- Microclimate - thermal/RH protection
- Food storage (H_2O; seed at high RH)
- But, accumulation of gases
  - Ammonia
  - Carbon dioxide





Mobility

- Avoiding high soil surface temperature
  - Stilting, side-winding, rolling, darting

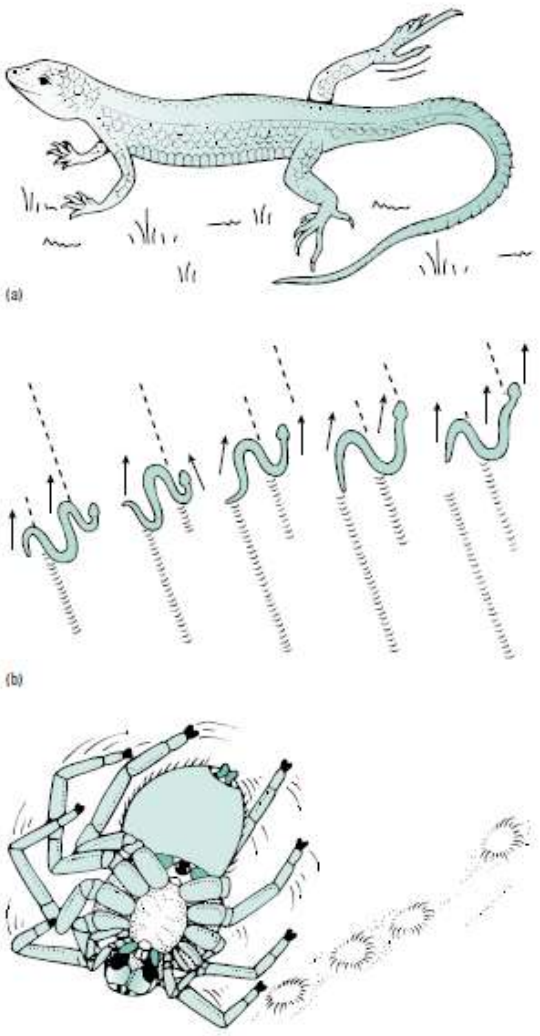


Fig. 16.9 Methods of locomotion on hot sand. (a) Tiptoe stance in lizards (also shown in long-legged insects). (b) Sidewinding snakes, allowing reduced contact with sand. (c) Cartwheeling down dunes in the spider *Carpachne*. (b, Adapted from Pough *et al.* 1999; c, adapted from Henschel 1990.)

Thermal Tolerance

- High upper critical temperature
  - Arthropods 45-47 °C
  - "hot ants" 51.5 °C!
  - Some vertebrates ≥ 45 °C

- Low SMR/BMR
- Q_{10} adaptation:
  low Q_{10} at intermediate T_a

Table 8.6 Upper critical temperature (UCT) for a variety of animals from different habitats.

Group	Example (habitat)	UCT (°C)
Insects	*Lepisma* (land springtail)	36
	Thermobia (land firebrat)	40+
	Sphingonotus (land moth)	41
	Bembex (land sandwasp)	42
	Onymacris (desert beetle)	49–51
	Dasymutilla (land sandwasp)	52
	Ocymyrmex (desert ant)	51.5
	Melophorus (desert ant)	54
Arachnids	*Buthotus* (land scorpion)	45
	Leiurus (land scorpion)	47
Vertebrates		
Fish	*Pagothenia* (polar SW)	6–10
	Fundulus (cold SW)	35
Amphibians	Salamanders (FW/land)	29–35
	Anurans (FW/land)	36–41
Reptiles	Alligators (land/FW)	38
	Turtles (SW/land)	41
	Lizards (land/desert)	40–47
	Snakes (land)	40–42
Birds	Passerines	46–47
	Nonpasserines	44–46
Mammals	Monotremes	37
	Marsupials	40–41
	Placentals	42–44

FW, fresh water; SW, sea water.

Control of water loss

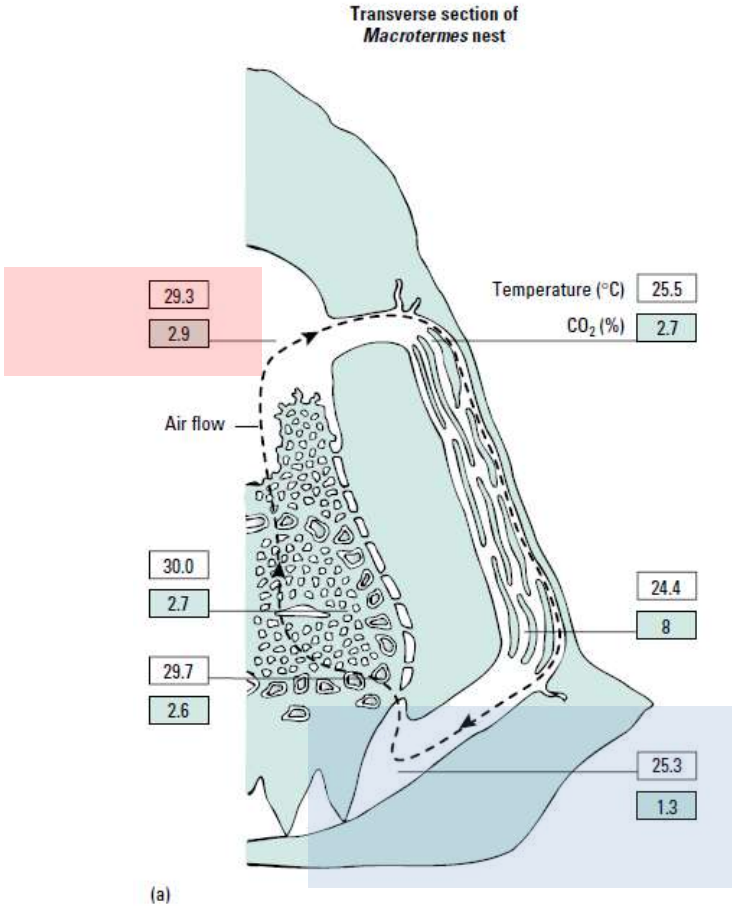
- Cutaneous resistance (1 sec cm^{-1} for a free water surface)

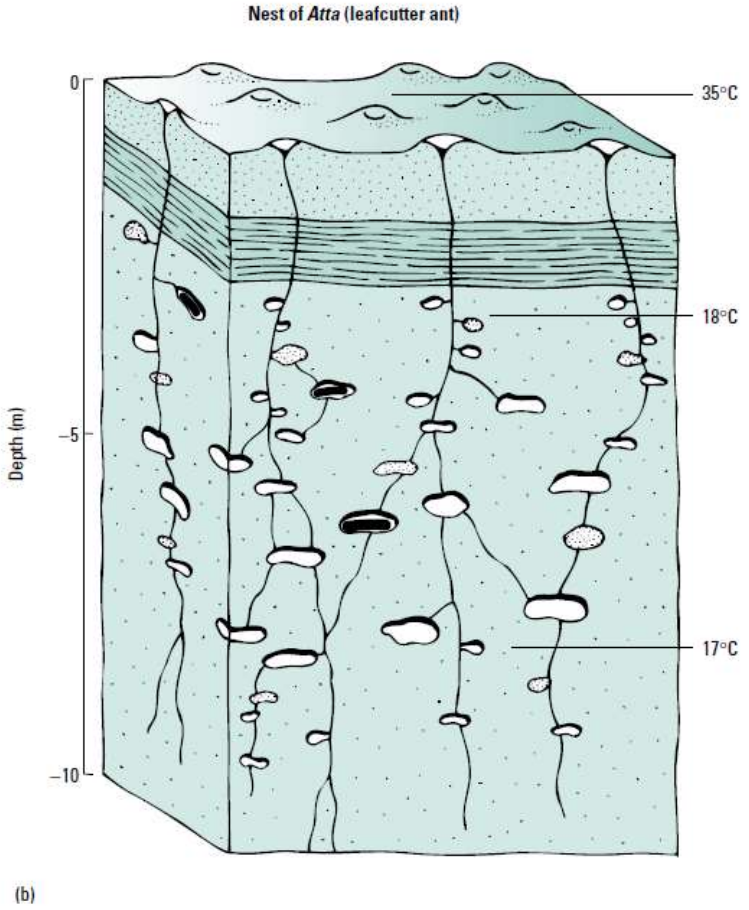
Red-eyed tree frog in water conserving posture

Animal group/ genus	Resistance (s cm^{-2})	Water flux (mg cm^{-2} h^{-1})	Transpiration rate (µg cm^{-2} h^{-1} $mmHg^{-1}$)
Arthropods			
Insects			
Thermobia (apterygote)			15
Ctenolepisma (apterygote)			0.7
Rhodnius (bug)			12
Geocoris (bug)			14
Arenivaga (cockroach)			12–80
Diceroprocta (cicada)			100
Locusta (locust)		0.70	
Onymacris (beetle)	5030	0.10	3.1
Centrioptera (beetle)			6.3
Cryptoglossa (beetle)			8.4
Lepidochora (beetle)			3.1
Tenebrio (beetle larva)			5
(beetle pupa)			1
Eleodes (beetle)		0.20	17
Glossina (tsetse fly)			8
(pupa)			0.3
Manduca (caterpillar)			40
Anaphes (wasp)			4–8
Pogonomyrmex (ant)			26
Messor (ant)			18
Vertebrates			
Pternohyla (frog, cocooned)	457		
Gopherus (tortoise)	120	1.56	
Sauromalus (lizard)	1360		
Dipsosaurus (lizard)		0.13	
Gehydra (lizard)		0.22	
Pitnophis (snake)		0.23	
Struthio (ostrich)	158	1.73	
Dipodomys (kangaroo rat)		0.53	
Gerbillus (gerbil)			
Peromyscus (cactus mouse)		0.66	
Capra (desert goat)		2.10	
Oryx		3.2–5.9	
Megaleia (red kangaroo)			
Camelus (dromedary)			

Manipulation of microclimates

- Burrows, nests
  - ants, termites

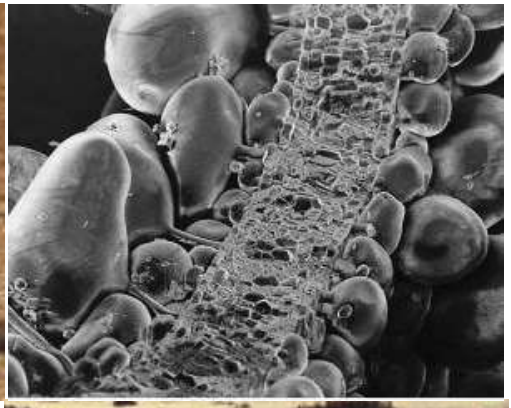




Diet – getting the right food

- Herbivory
  - High salt: chisel-tooth kangaroo rats eat *Atriplex*: chisel-tooth scrapes off salt

- Nectarivory

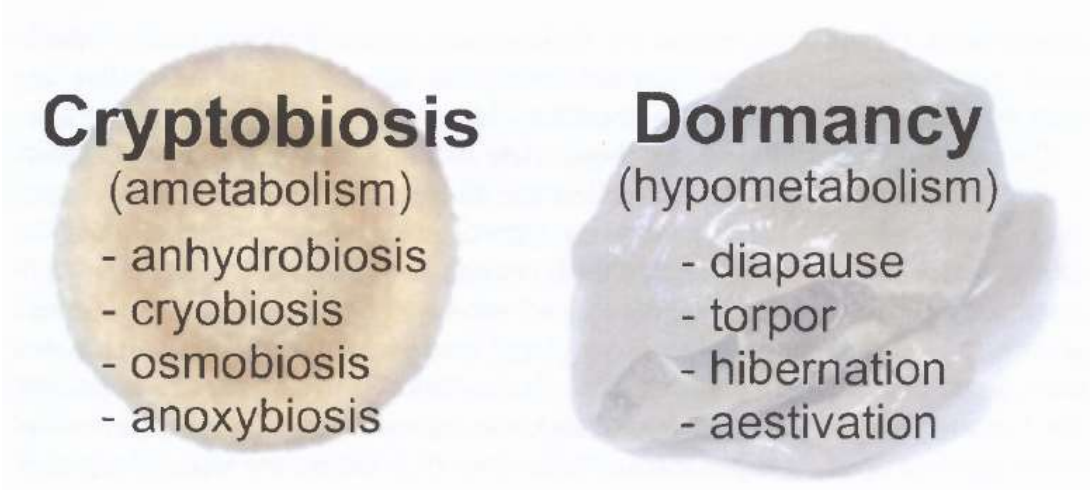


- Carnivory

- Granivory
  - Storage: underground
    fur-lined cheek pouches

Aestivation

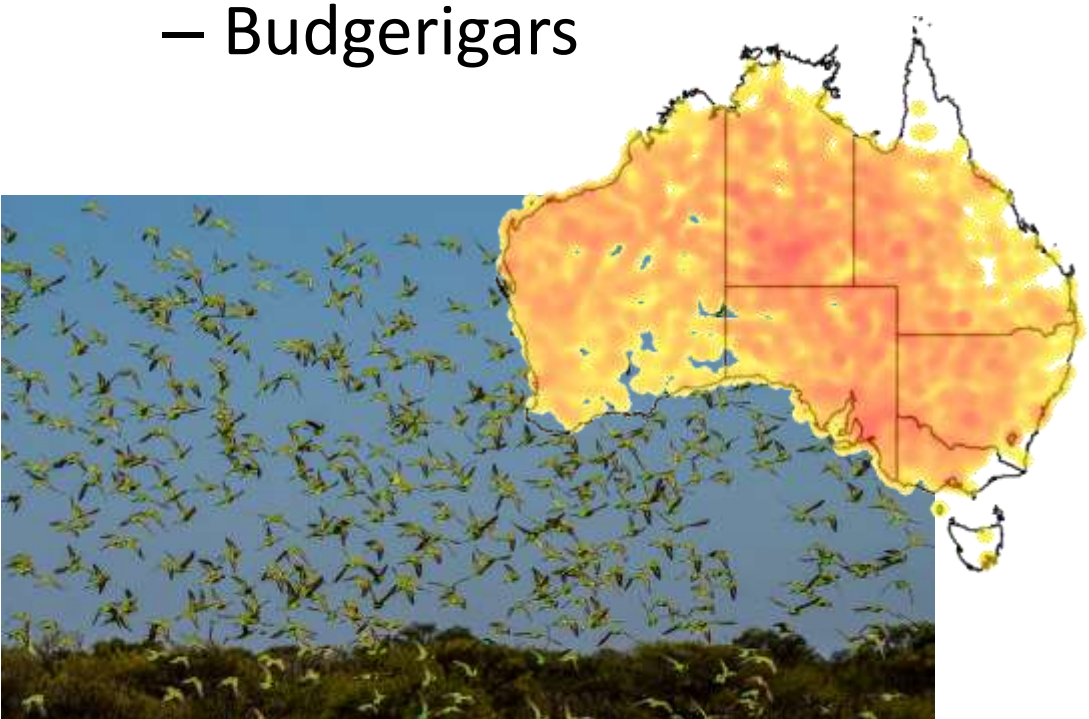
METABOLIC DEPRESSION

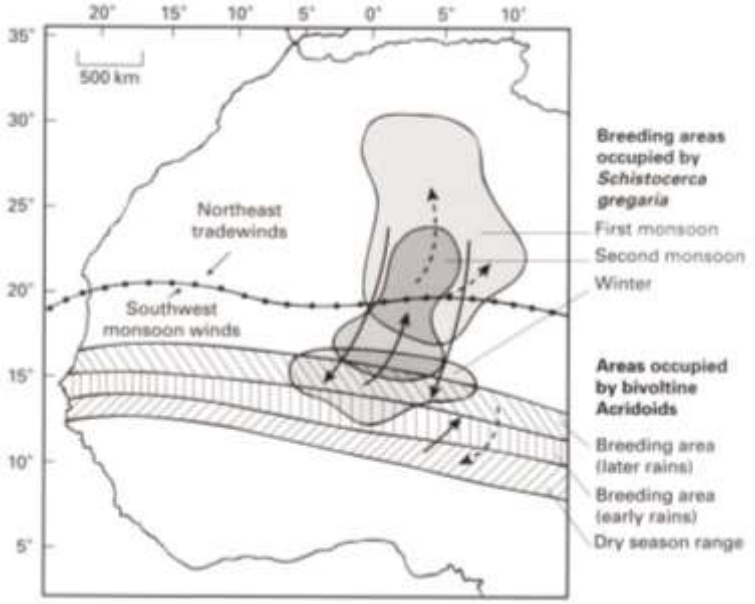


← Tracking an aestivating Western Swamp Tortoise

Migration

- When the going gets bad, get going (elsewhere)
- Nomadism
  - Desert locust (*Schistocerca gregaria*)
  - Budgerigars





Strategies in hot dry environments

Evaporators

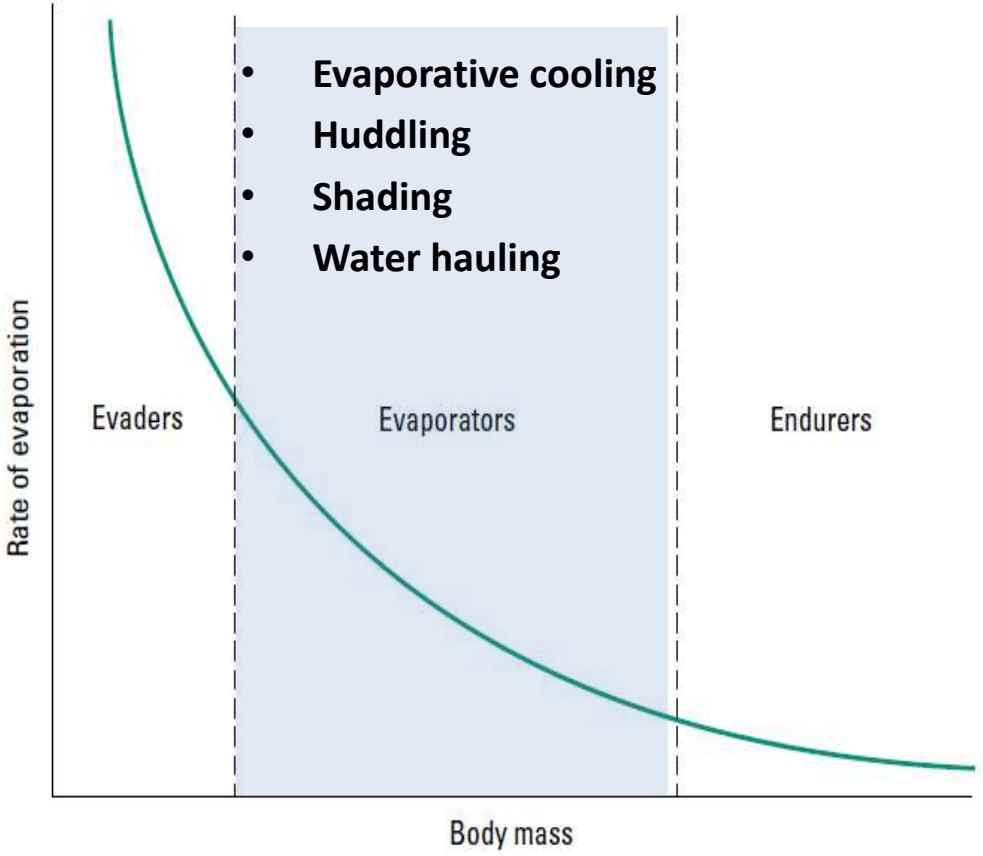


Fig. 16.7 Three main strategies for desert animals, in relation to size and rate of evaporation.

Evaporative cooling

- Mammals/Birds
  - Panting, sweating, gular flutter
- Insects
  - Desert cicadas (*Diceroprocta, Okanagodes*) “sweat”:
    T_b 39-45 ^oC at T_a = 50 ^oC

  - Grasshopper (*Poekilocerus*) and xylem feeders have ample water for evaporative cooling

Huddling, shading and water haulage

- bee-eaters, etc

  huddle and save 30% of daily energy expenditure and water

- many birds shade their young

- Sandgrouse

  carry water in breast feathers to young

Strategies in hot dry environments

Endurers

- Adaptive Hyperthermia

Increasing T_b at high T_a

  - Keeps a positive thermal gradient for passive heat loss
  - Minimises the requirement for evaporative water loss

Camels

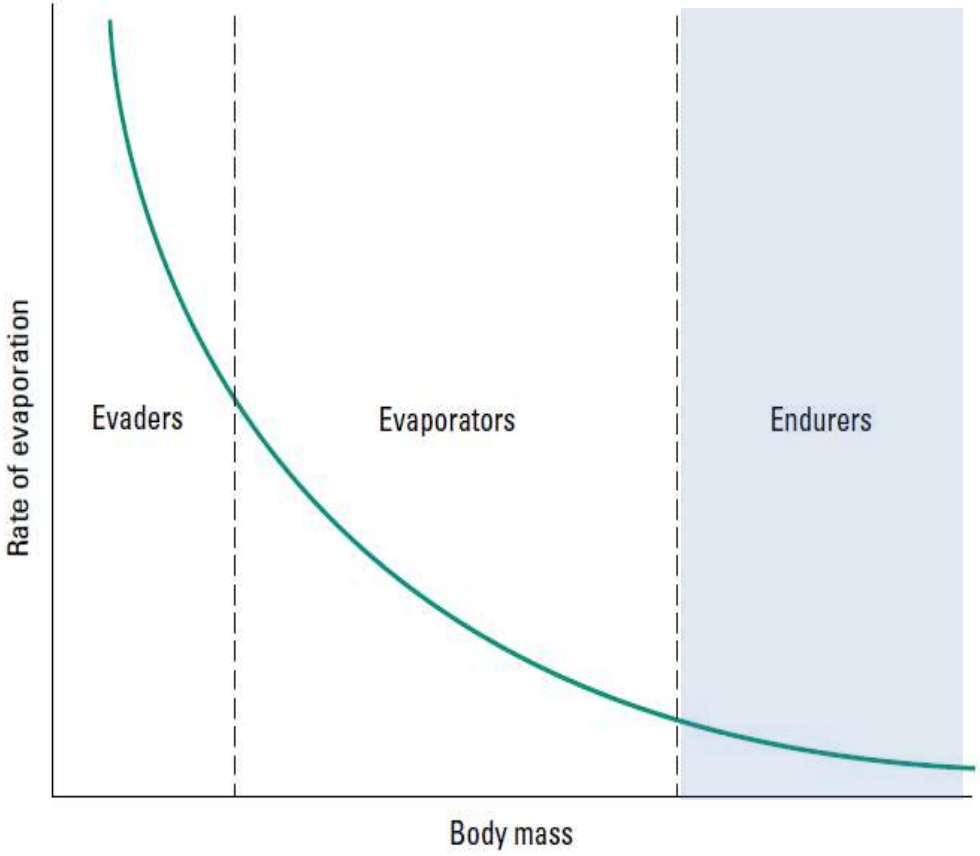


Fig. 16.7 Three main strategies for desert animals, in relation to size and rate of evaporation.